41. A method of making a directional microphone apparatus with a steerable beam, comprising:

providing a microphone array;

providing a diffracting structure within said microphone array to increase the effective path length across said array, said microphone array and diffracting structure being associated with a characteristic sound field describing the properties thereof;

determining the sound field around said array and said diffracting structure; and

providing a processor programmed to process signals from individual microphones in said microphone array to create a steerable beam, said signals being weighted according the location of said individual microphones and the determined properties of said sound field.

B2

42. A method as claimed in claim 41, wherein said diffracting structure is constructed so that surface waves can form over its surface and thereby modify the travel time of sound waves across said array.

43. A method as claimed in claim 41, wherein said diffracting structure is located within a space confined by said microphones of said microphone array.

44. A method as claimed in claim 43, wherein said sound field is determined by identifying a point source in a space around said diffracting structure, and calculating the sound field around said microphone structure from the field generated by said point source.

45. A method as claimed in claim 44, wherein said sound field is determined by solving an acoustic wave equation to determine the sound pressure over said diffracting surface.

46. A method as claimed in claim 45, wherein said acoustic wave equation is solved by setting the appropriate boundary conditions for said diffracting structure.

47. A method as claimed in claim 46, wherein said acoustic equation has a solution of the form $p(r) = F(r, r0)$, where r is a position vector and r_0 is either a signal source position vector or a noise source position.

48. A method as claimed in claim 47, wherein the impedance boundary condition for said diffracting structure is given by the equation page 20

$$\left[\frac{dp}{dn} + ik\beta p\right]_S =$$

wherein n is the outward unit normal and β is the normalized specific admittance.

49. A method as claimed in claim 48, wherein the solution to said acoustic wave equation is evaluated at each microphone position.

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50. A method as claimed in claim 49, wherein steerable beam directions for said array are created by combining signals from each of said microphones based on said solutions evaluated at each microphone position.

51. A method as claimed in claim 50, wherein said signals are combined with time delays that depend on the solutions to said acoustic wave equation evaluated at the respective microphone positions.

52. A method as claimed in claim 51, wherein the signals from different microphones are weighted by optimizing the expression

$$E\{G(\omega)\} = \frac{e^{-\sigma_p^2}(\mathbf{W_0}^H \mathbf{R}_{ss}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H \mathrm{diag}(\mathbf{R}_{ss}(\omega))\mathbf{W_0})}{e^{-\sigma_p^2}(\mathbf{W_0}^H \mathbf{R}_{nn}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H \mathrm{diag}(\mathbf{R}_{nn}(\omega))\mathbf{W_0})}$$ page 15

where

$E(G(w))$ is the expected gain,
σ_m^2 is the variance of the magnitude fluctuations due to microphone tolerance,
σ_p^2 is the variance of the phase fluctuations due to microphone tolerance,
R_{ss} is a signal correlation matrix,
R_{nn} is a noise correlation matrix,

W_0, is a nominal value vector of weights assigned to each microphone in the array.

53. A method as claimed in claim 52, wherein said signal correlation matrix R_{ss} is derived from the equation

$$R_{ss}(\omega) = E\{S \bullet S^H\} / \sigma^2$$

and said noise correlation matrix is derived from the equation

$$R_{nn}(\omega) = E\{N \bullet N^H\} / \sigma^2$$

54. A method as claimed in claim 52, wherein said expression is optimized by maximization.

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55. A method as claimed in claim 51, the surface of said diffracting structure is configured to modify the acoustic impedance thereof. species II

56. A method as claimed in claim 55, wherein the surface of said diffracting structure is provided with surface damping. II

57. A method as claimed in claim 55, wherein the surface impedance of said diffracting structure has a spring-like reactance to enhance the propagation of surface waves. II

58. A method as claimed in claim 55, wherein the surface of said diffracting structure has an open-cellular structure. II

59. A method as claimed in claim 58, wherein the lateral size of the cells forming said cellular structure is a fraction of the wavelength of the sound. II

60. A method as claimed in claim 59, wherein the microphones are located in said cells away from pressure nodal points. II

61. A method as claimed in claim 51, wherein said diffracting structure is in the form of a body with upwardly and outwardly sloping side walls, and said microphones are located at said side walls so that sound waves propagating across said array must travel around said body, or outwardly and over the top of

species III

said body.

62. A method as claimed in claim 61, wherein said body is in the form of an inverted cone or frusto-cone.

63. A method of steering a beam in a directional microphone apparatus having a microphone array and a diffracting structure within said microphone array to increase the effective path length across said array, comprising:

receiving signals from individual microphones in said array; and

combining said signals to form a steerable beam based on a predetermined sound field that takes into account the free space properties of said array and the effects of said diffracting structure.

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64. A method as claimed in claim 63, wherein said signals are combined with a time delay that takes into account the propagation times across said array and the effects of said diffracting structure.

65. A method as claimed in claim 64, wherein said signals are summed to form a steerable beam.

66. A method as claimed in claim 65, wherein said signals are weighted prior to being summed.

67. A method as claimed in claim 64, wherein the time delays are set according to the equation

$$\omega \tau_m = -\arg[F(\mathbf{r}_m, \mathbf{r}_l)]$$

68. A method as claimed in claim 63, wherein said diffracting structure is a sphere and sound field is determined in accordance with the equation

$$F(\mathbf{r}, \mathbf{r}_o) = iC \sum_{n=0}^{\infty} (2n+1) P_n(\cos\psi)\, h_n^{(1)}(kr_>) \left[j_n(kr_<) - a_n h_n^{(1)}(kr_<) \right]$$

where ψ is the angle between vectors $\boldsymbol{r}$ and r_o, P_n is the Legendre polynomial of order n, j_n is the spherical Bessel function of the first kind and order n, $h_n^{(1)}$ is the spherical Hankel function of the first kind and order n, $r_< = \min(r, r_0)$, n, $r_> = \max(r, r_0)$, and

$$a_n = j_n'(ka)/h_n^{(1)\prime}(ka)$$

69. A microphone apparatus with passive beam steering, comprising:

a microphone;

a diffracting structure within a space confined by said microphones of said microphone array to increase the effective path length across said array, said microphone array and diffracting structure being associated with a characteristic sound field describing the properties thereof; and

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a processor programmed to process weighted signals from individual microphones in said microphone array to create a steerable beam based on the location of said individual microphones and the predetermined properties of said sound field taking into account the modifying effect of said diffracting structure.

70. An apparatus as claimed in claim 69, wherein said diffracting structure is constructed so that surface waves can form over its surface and thereby modify the travel time of sound waves across said array.

71. An apparatus as claimed in claim 69, wherein said processor combines said signals with a time delay that takes into account the propagation times across said array and the effects of said diffracting structure.

72. An apparatus as claimed in claim 71, wherein said processor is programmed to sum said signals to form a steerable beam.

73. An apparatus as claimed in claim 72, wherein said processor is programmed to weight said signals prior to summing them.

74. An apparatus as claimed in claim 72, wherein the time delays are set according to the equation

$$\omega \tau_m = -\arg[F(\mathbf{r}_m, \mathbf{r}_l)]$$

75. An apparatus as claimed in claim 74, wherein said diffracting structure is a sphere and said sound field is determined in accordance with the equation

$$F(\mathbf{r}, \mathbf{r}_o) = iC \sum_{n=0}^{\infty} (2n+1) P_n(\cos\psi)\, h_n^{(1)}(kr_>)\,[\,j_n(kr_<) - a_n h_n^{(1)}(kr_<)]$$

where ψ is the angle between vectors r and r_o, P_n is the Legendre polynomial of order n, j_n is the spherical Bessel function of the first kind and order n, $h_n^{(1)}$ is the spherical Hankel function of the first kind and order n, $r_< = \min(r, r_0)$, n, $r_> = \max(r, r_0)$, and

$$a_n = j_n'(ka)/h_n^{(1)\prime}(ka)$$

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76. An apparatus as claimed in claim 69, wherein the surface of said diffracting structure is configured to modify the acoustic impedance thereof. Species II

77. An apparatus as claimed in claim 76, wherein the surface of said diffracting structure is provided with surface damping. II

78. An apparatus as claimed in claim 76, wherein the surface impedance of said diffracting structure has a spring-like reactance to enhance the propagation of surface waves. II

79. An apparatus as claimed in claim 76, wherein the surface of said diffracting structure has an open-cellular structure. II

80. An apparatus as claimed in claim 79, wherein the lateral size of the cells forming said cellular structure is a fraction of the wavelength of the sound. II

81. An apparatus as claimed in claim 80, wherein the microphones are located in said cells away from pressure nodal points. II

82. A method of improving a performance of a microphone array confining a diffracting structure by determining weights to be assigned to each microphone in a microphone array when processing an input from each

microphone, the method comprising:

(a) determining an expression for an expected gain of said array, said expression being dependent on said weights assigned to each variable representing an input from a microphone, and

(b) maximizing said expression,

wherein said expression also contains variables representing a variance of magnitude fluctuations from inputs from said microphone and a variance of phase fluctuations from said inputs from said microphone.

83. A method as in claim 82 wherein said expression is:

$$E\{G(\omega)\} = \frac{e^{-\sigma_p^2}(\mathbf{W_0}^H\mathbf{R}_{ss}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H \mathrm{diag}(\mathbf{R}_{ss}(\omega))\mathbf{W_0})}{e^{-\sigma_p^2}(\mathbf{W_0}^H\mathbf{R}_{nn}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H \mathrm{diag}(\mathbf{R}_{nn}(\omega))\mathbf{W_0})}$$

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where

E(G(w)) is the expected gain,

σ_m^2 is the variance of the magnitude fluctuations due to microphone tolerance,

σ_p^2 is the variance of the phase fluctuations due to microphone tolerance,

R_{ss} is a signal correlation matrix,

R_{nn} is a noise correlation matrix,

W_0, is a nominal value vector of weights assigned to each microphone in the array.

84. A method as in claim 83 wherein step (b) is accomplished by setting the vector W_0, equal to the eigenvector which corresponds to the maximum eigenvalue of the symmetric matrix

$$A^{-1}B$$

where

$$A = \left(e^{-\sigma_p^2}\mathbf{R}_{nn}(\omega) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)\mathrm{diag}(\mathbf{R}_{nn}(\omega))\right)$$

$$B = \left(e^{-\sigma_p^2}\mathbf{R}_{ss}(\omega) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)\mathrm{diag}(\mathbf{R}_{ss}(\omega))\right)$$

85. A microphone apparatus as claimed in claim 69, wherein signals from said microphones are processed using the following method:

(aa) determining an expression for an expected gain of said array, said expression being dependent on weights assigned to each signal from a microphone in the array, and

(ab) maximizing said expression,

wherein said expression also contains variables representing a variance of magnitude fluctuations from inputs from said microphone and a variance of phase fluctuations from said inputs from said microphone.

86. A microphone apparatus as claimed in claim 85 wherein said expression is

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$$E\{G(\omega)\} = \frac{e^{-\sigma_p^2}(\mathbf{W_0}^H\mathbf{R}_{ss}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H \mathrm{diag}(\mathbf{R}_{ss}(\omega))\mathbf{W_0})}{e^{-\sigma_p^2}(\mathbf{W_0}^H\mathbf{R}_{nn}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H \mathrm{diag}(\mathbf{R}_{nn}(\omega))\mathbf{W_0})}$$

where

E(G(w)) is the expected gain,

σ_m^2 is the variance of the magnitude fluctuations due to microphone tolerance,

σ_p^2 is the variance of the phase fluctuations due to microphone tolerance,

R_{ss} is a signal correlation matrix,

R_{nn} is a noise correlation matrix,

W_0, is a nominal value vector of weights assigned to each microphone in the array.

87. A microphone apparatus as claimed in claim 86 wherein step (ab) is accomplished by setting the vector W_0 equal to the eigenvector which corresponds to the maximum eigenvalue of the symmetric matrix

$$A^{-1}B$$

where

$$A = \left(e^{-\sigma_p^2}\mathbf{R}nn(\omega) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)\mathrm{diag}(\mathbf{R}_{nn}(\omega))\right)$$

$$B = \left(e^{-\sigma_p^2}\mathbf{R}_{ss}(\omega) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)\mathrm{diag}(\mathbf{R}_{ss}(\omega))\right)$$

88. A method of determining the optimum weights to form a beam for signals from an array of microphones confining a diffracting structure, comprising steps pf:

generating solutions of the form $p(r) = F(r,r0)$ for a source at position r_0 to a wave equation of the form $\nabla^2 p + k^2 p = \delta(r-r_0)$;

for a selected talker position, calculating signal components received at each microphone;

forming a vector of said calculated signal components and determining signal power and the signal correlation matrix R_{ss};

for noise sources at many different positions determining the noise components at each microphone in the array;

forming a vector of said noise components and determining the noise power and noise correlation matrix R_{nn}; and

generating optimum weights for said microphones based on said calculations.

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89. A method as claimed in claim 88, further comprising specifying the magnitude and phase of microphone gain tolerances and obtaining the optimal weight vector W_0 by maximizing the expectation value of the gain in the equation

$$E\{G(\omega)\} = \frac{e^{-\sigma_p^2}(\mathbf{W_0}^H\mathbf{R}_{ss}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H\mathrm{diag}(\mathbf{R}_{ss}(\omega))\mathbf{W_0})}{e^{-\sigma_p^2}(\mathbf{W_0}^H\mathbf{R}_{nn}(\omega)\mathbf{W_0}) + \left(1 - e^{-\sigma_p^2} + \sigma_m^2\right)(\mathbf{W_0}^H\mathrm{diag}(\mathbf{R}_{nn}(\omega))\mathbf{W_0})}$$

where

$E(G(w))$ is the expected gain,

σ_m^2 is the variance of the magnitude fluctuations due to microphone tolerance,

σ_p^2 is the variance of the phase fluctuations due to microphone tolerance,

R_{ss} is a signal correlation matrix,

R_{nn} is a noise correlation matrix,